Clausewitz, Nonlinearity, and the Unpredictability of War

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Although our intellect always longs for clarity and certainty, our nature often finds uncertainty fascinating.

Clausewitz, *On War*, Book One, Chapter 1.

Despite the frequent invocations of his name in recent years, especially during the Gulf War, there is something deeply perplexing about the work of Carl von Clausewitz (1780–1831). In particular, his unfinished magnum opus *On War* seems to offer a theory of war, at the same time that it perversely denies many of the fundamental preconditions of theory as such—simplification, generalization and prediction, among others.[1] The book continues to draw the attention of both soldiers and theorists of war, although soldiers often find the ideas of Clausewitz too philosophical to appear practical, while analysts usually find his thoughts too empirical to seem elegant. Members of both groups sense that there is too much truth in what he writes to ignore him. Yet, as the German historian Hans Rothfels has bluntly put it, Clausewitz is an author "more quoted than actually read."[2] Lofty but pragmatic, by

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1. Carl von Clausewitz, *On War,* ed. and trans. Michael Howard and Peter Paret (Princeton: Princeton University Press, 1976). I use this edition for all quotations from *On War* in English unless otherwise indicated. For the German, see *Vom Kriege*, 18th ed. (complete edition of original text), ed. Werner Hahlweg (Bonn: Dümmlers, 1973). For other works in English, see von Clausewitz, *Historical and Political Writings,* ed. and trans. Peter Paret and Daniel Moran (Princeton: Princeton University Press, 1992).
2. Hans Rothfels, "Clausewitz," in Edward Mead Earle, ed., *Makers of Modern Strategy* (New York: Atheneum, 1969), p. 93. Christopher Bassford offers one impression of the reception of Clausewitz's work in his study of the Anglo-American reception of Clausewitz, 1815–1945 (Oxford: Oxford University Press, in press).

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a theorist who repudiated conventional meanings of theory, *On War* endures as a compelling and enigmatic classic.

Just what *is* the difficulty with Clausewitz that makes his work so significant yet so difficult to assimilate? *On War*'s admirers have sensed that it grapples with war's complexity more realistically than perhaps any other work. Its difficulty, however, has prompted different explanations even among Clausewitz partisans. Raymond Aron has spoken for those who believe that the incomplete and unpolished nature of *On War* is the primary source of misunderstanding: as Clausewitz repeatedly revises his treatise, he comes to a deeper understanding of his own ideas, but before his untimely death he brings his fully developed insights to bear only upon the final revision of Chapter 1 of Book One.[3]

A second approach to the question is exemplified by Peter Paret's stress on the changing interpretation of any significant author over time. Clausewitz's writings have suffered more distortions than most, Paret has suggested, because abstracting this body of work from its times does violence to its insistence on unifying the universal with the historical particular. Thus for Paret the literature on Clausewitz has been "fragmented and contradictory in its findings" because of our lack of historical consciousness.[4]

A third route to explaining the difficulties encountered in coping with *On War* has been typified by Michael Handel, for whom the issue is not so much changes in our interpretations as changes in warfare itself. Those aspects of *On War* that deal with human nature, uncertainty, politics, and rational calculation "will remain eternally valid," he contended. "In all other respects technology has permeated and irreversibly changed every aspect of warfare."[5] For Handel, the essential problem in understanding Clausewitz lies in our confrontation with a reality qualitatively different from his.

Each of these approaches has merit, yet none satisfies completely. I offer a revision of our perception of Clausewitz and his work by suggesting that

3. Raymond Aron, *Clausewitz: Philosopher of War*, trans. Christine Booker and Norman Stone (London: Routledge and Kegan Paul, 1983), p. 6. Original *Penser la guerre, Clausewitz*, 2 vols. (Paris: Gallimard, 1976). The suggestion has recently been made that the text was actually much more finished than has hitherto been thought: Azar Gat, "Clausewitz's Final Notes," *Militärgeschichtliche Mitteilungen*, Vol. 45, No. 1 (1989), pp. 45–50.
4. Peter Paret, *Clausewitz and the State: The Man, His Theories and His Times* (Princeton: Princeton University Press, 1985), pp. 8–9 (originally published by Oxford University Press, 1976). Azar Gat's argument, that Clausewitz's work is best understood as part of the Romantic backlash against the Enlightenment, also belongs to this approach. See Gat, *The Origins of Military Thought: From the Enlightenment to Clausewitz* (Oxford: Oxford University Press, 1989).
5. Michael I. Handel, *War, Strategy and Intelligence* (London: Frank Cass, 1989), p. 60.

Clausewitz displays an intuition concerning war that we can better comprehend with terms and concepts newly available to us: *On War* is suffused with the understanding that every war is inherently a nonlinear phenomenon, the conduct of which changes its character in ways that cannot be analytically predicted. I am not arguing that reference to a few of today's "nonlinear science" concepts would help us clarify confusion in Clausewitz's thinking. My suggestion is more radical: in a profoundly unconfused way, he understands that seeking exact analytical solutions does not fit the nonlinear reality of the problems posed by war, and hence that our ability to predict the course and outcome of any given conflict is severely limited.

The correctness of Clausewitz's perception has both kept his work relevant and made it less accessible, for war's analytically unpredictable nature is extremely discomfiting to those searching for a predictive theory. An approach through nonlinearity does not make other reasons for difficulty in understanding *On War* evaporate. It does, however, provide new access to the realistic core of Clausewitz's insights and offers a correlation of the representations of chance and complexity that characterize his work. Furthermore, it may help us remove some unsettling blind spots that have prevented us from seeing crucial implications of his work.

What is "Nonlinearity"?

"Nonlinearity" refers to something that is "not linear." This is obvious, but since the implicit structure of our words often reveals hidden habits of mind, it is useful to reflect briefly on some tacit assumptions. Like other members of a large class of terms, "nonlinear" indicates that the norm is what it negates. Words such as *aperiodic* or *asymmetrical, disproportionate* or *discontinuous, disequilibrium* or *nonequilibrium* are deeply rooted in a cultural heritage that stems from the classical Greeks. The underlying notion is that "truth" resides in the simple (and thus the stable, regular, and consistent) rather than in the complex (and therefore the unstable, irregular, and inconsistent).[6]

The result has been an authoritative guide for our Western intuition, but one that is idealized and liable to mislead us when the surrounding world and its messy realities do not fit this notion. An important basis for confusion is association of the norm not only with simplicity, but with obedience to

6. Alan Beyerchen, "Nonlinear Science and the Unfolding of a New Intellectual Vision," *Papers in Comparative Studies*, Vol. 6 (1988–89), pp. 26–29.

rules and thus with expected behavior—which places blinders on our ability to see the world around us. Nonlinear phenomena are thus usually regarded as recalcitrant misfits in our catalog of norms, although they are actually more prevalent than phenomena that conform to the rules of linearity. This can seriously distort perceptions of what is central and what is marginal—a distortion that Clausewitz as a realist understands in *On War*.

"Linear" applies in mathematics to a system of equations whose variables can be plotted against each other as a straight line. For a system to be linear it must meet two simple conditions. The first is *proportionality*, indicating that changes in system output are proportional to changes in system input. Such systems display what in economics is called "constant returns to scale," implying that small causes produce small effects, and that large causes generate large effects. The second condition of linearity, called *additivity* or superposition, underlies the process of analysis. The central concept is that the whole is equal to the sum of its parts. This allows the problem to be broken up into smaller pieces that, once solved, can be added back together to obtain the solution to the original problem.[7]

Nonlinear systems are those that disobey proportionality or additivity. They may exhibit erratic behavior through disproportionately large or disproportionately small outputs, or they may involve "synergistic" interactions in which the whole is not equal to the sum of the parts.[8] If the behavior of a system can appropriately be broken into parts that can be compartmentalized, it may be classified as linear, even if it is described by a complicated equation with many terms. If interactions are irreducible features of the

7. The principle of proportionality means that if f is a function or an operator, a is a constant, and u is the system input (either a variable or itself a function), then $f(au) = af(u)$. A more precise way of stating the principle of additivity is that the effect of adding the system inputs together first and then operating on their sum is equivalent to operating on two inputs separately and then adding the outputs together, so that $f(u_1 + u_2) = f(u_1) + f(u_2)$. If f does not meet both of these conditions, it is nonlinear. In effect, if a system can be described adequately by the mathematical operations of addition, subtraction, multiplication by a constant, integration with respect to time or differentiation with respect to time, it can appropriately be thought of as linear. If it is necessary to multiply or divide variables by each other, raise to powers, extract roots, or integrate or differentiate with respect to dependent variables (that is, variables other than time), then the system is nonlinear.

8. The meaning of a "synergistic" interaction is indicated by the contrast between a common linear operation and a common nonlinear one. A linear operation such as multiplying by a constant obeys the principle of additivity: let $f(u) = au$, then $f(u_1 + u_2) = a(u_1 + u_2) = au_1 + au_2$, which is just $f(u_1) + f(u_2)$ again. A nonlinear operation such as squaring, however, is different: let $f(u) = u^2$, then $f(u_1 + u_2) = (u_1 + u_2)^2$, which equals not just $u_1^2 + u_2^2$ again, but $u_1^2 + u_2^2$ plus the interaction term $2u_1u_2$.

system, however, it is nonlinear even if described by relatively simple equations.

Nonlinear phenomena have always abounded in the real world.[9] But often the equations needed to describe the behavior of nonlinear systems over time are very difficult or impossible to solve analytically. Systems with feedback loops, delays, "trigger effects," and qualitative changes over time produce surprises, often abruptly crossing a threshold into a qualitatively different regime of behavior. The weather, fluid turbulence, combustion, breaking or cracking, damping, biological evolution, biochemical reactions in living organisms, and hysteresis in electronic systems offer examples of nonlinear phenomena. Although some analytical techniques have been generated over the centuries to cope with systems characterized by nonlinearity, until the advent of numerical techniques offered by computers its study has been relatively limited.[10]

In contrast, sophisticated analytical techniques for solving linear equations have been developed over the centuries, becoming the preferred tools in nearly all technical fields by the latter portion of the nineteenth century. Due to the structural stability of a linear system, once we know a little about it we can calculate and predict a great deal. The normal procedure has thus been to find mathematical techniques or physical justification for an idealized "linearization" of a natural or technological system. Such an idealized version of a system is often constructed by throwing out the nonlinear terms in the laws adduced to describe it and working with the much simpler linear "approximation." In commonly used terms, one thus goes from equations that "blow up" to those that are "well-behaved." In fact, mathematician Ian Stewart has noted: "Classical mathematics concentrated on linear equations for a sound pragmatic reason: it couldn't solve anything else. . . . So docile are linear equations that the classical mathematicians were willing to compromise their physics to get them. So the classical theory deals with *shallow* waves, *low*-amplitude vibrations, *small* temperature gradients."[11] As is often

9. The mathematician Stanislaw Ulam suggested that calling natural phenomena *non*linear is like referring to the bulk of the animal kingdom as "non-elephant animals." David Campbell, "Nonlinear Science: From Paradigms to Practicalities," *Los Alamos Science*, Vol. 15, Special Issue (1987), p. 218.
10. See, for example, Larry Smarr, "An Approach to Complexity: Numerical Computations," *Science*, Vol. 228 (April 26, 1985), pp. 403–408; and Norman Zabusky, "Grappling with Complexity," *Physics Today*, October 1987, pp. 25–27.
11. Ian Stewart, *Does God Play Dice? The Mathematics of Chaos* (Oxford and New York: Basil Blackwell, 1989), p. 83.

the case, reality has been selectively addressed in order to manipulate it with the tools available. Clausewitz pointedly contrasted his own approach with the implicit dependence upon such selectivity among military theorists of his era, such as Heinrich von Bülow or Antoine-Henri de Jomini.[12]

The resort to idealized linearizations has been legitimated by the assumption, increasingly dubious, that reality is ultimately simple and stable. This assumption works well for linear systems, and even relatively well for those nonlinear systems that are stable enough to be treated using the techniques of linear analysis or control theory. But it turns out to be misleading when applied to the many more systems that are unstable under even small perturbations. As Stewart implied, this was understood by the more thoughtful of the classical mathematicians and physicists. James Clerk Maxwell, one of the greatest scientists of the nineteenth century, displayed a keen awareness of the limitations of assuming that systems in the real world are structurally stable:

> When the state of things is such that an infinitely small variation of the present state will alter only by an infinitely small quantity the state at some future time, the condition of the system, whether at rest or in motion, is said to be stable; but when an infinitely small variation in the present state may bring about a finite difference in the state of the system in a finite time, the condition of the system is said to be unstable. It is manifest that the existence of unstable conditions renders impossible the prediction of future events, if our knowledge of the present state is only approximate, and not accurate. . . . It is a metaphysical doctrine that from the same antecedents follow the same consequents. No one can gainsay this. But it is not of much use in a world like this, in which the same antecedents never again concur, and nothing ever happens twice. . . . The physical axiom which has a somewhat similar aspect is 'That from like antecedents follow like consequents.' But here we have passed from sameness to likeness, from absolute accuracy to a more or less rough approximation.[13]

Thus Maxwell held that analytical mathematical rules are not always reliable guides to the real world. We must often rely on statistical probabilities or approximate solutions reached by numerical techniques.

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12. See the treatment of Jomini and Bülow in Paret, *Clausewitz and the State*, passim; also Clausewitz, *On War*, pp. 134, 136, and 158.
13. James Clerk Maxwell, "Science and Free Will," in Lewis Campbell and William Garnett, with a new preface and appendix by Robert H. Kargon, *The Life of James Clerk Maxwell* [1882] (New York: Johnson Reprint Corporation, 1969), pp. 440–442.

What is new is that computers have allowed us to attack nonlinear problems numerically, in the process highlighting patterns of instability that have captured scientific and popular imaginations alike. The various fields of "nonlinear science"—such as those that deal with solitons, fractals, cellular automata, and self-organizing systems far from thermodynamic equilibrium—have been stimulated and enhanced by powerful computer graphics techniques for scientific visualization or "mathematical experiments." Their shared aesthetic conceptions about the positive value of complexity create multiple connections among them.[14]

One of the most visible aspects of nonlinear science is the portion of nonlinear dynamics popularly known as "chaos theory." "Chaos" results when a system is nonlinear and "sensitive to initial conditions." This is the case even in a deterministic system for which the analytical laws and variables are known.[15] Such sensitivity is exactly what Maxwell meant: *immeasurably* small differences in input can produce entirely different outcomes for the system, yielding various behavior routes to a degree of complexity that exhibits characteristics of randomness—hence the term "chaos." For persons accustomed to expecting linear behavior, it is disconcerting that regions of deterministic chaos and predictable order can coexist for the same system. Furthermore, the very nature or definition of the system can change, and can do so rather abruptly, with transitions that usually depend on the *parameters of* the system more than on the *variables within* the system. In effect, parameters set the context, and the idealized boundaries they represent often contrast starkly with the indistinctness of boundaries in the real world.[16] In

14. See Beyerchen, "Nonlinear Science and the Unfolding," p. 31. A very good brief discussion of the mathematics and physics involved is in Campbell, "Nonlinear Science," pp. 218–262. The Sante Fe Institute is one of the key research centers where the implications of complexity across these fields is explored; see, for example, Daniel L. Stein, ed., Santa Fe Institute *Lectures in the Sciences of Complexity*, Vol. I (Redwood City, Calif.: Addison-Wesley, 1989).

15. For a readable, popular account of the development of this field, see James Gleick, *Chaos: The Making of a New Science* (New York: Viking, 1987), whose notes on sources indicate many of the seminal papers, yet notably lack the Russian achievements. For a more mathematically sophisticated, yet still accessible overview, see John L. Casti, *Reality Rules*, 2 vols. (New York: Wiley, 1992). As dissipative systems, wars also exhibit characteristics of nonlinear self-organization, but space does not here permit an exploration of this topic in Clausewitz's work. On self-organization, see Grégoire Nicolis and Ilya Prigogine, *Exploring Complexity: An Introduction* (New York: W.H. Freeman, 1989); and Peter Coveney and Roger Highfield, *The Arrow of Time: A Voyage through Science to Solve Time's Greatest Mystery* (New York: Fawcett Columbine, 1990).

16. Parameters are, after all, just certain variables treated as constants for the duration of the problem. The crucial role played by the parameters is readily apparent in contrasting the commonly studied motion of the simple pendulum for small oscillation amplitudes, with that

a chaotic regime, a system is dynamically unstable, so that nearly all input values for the variables lead to unpredictable, irregular behavior by the system.

Chaotic systems have raised some fundamental questions about relationships among order, randomness, and predictability, especially since the equations that represent them can be surprisingly simple. One of the first contemporary examples of chaos was encountered in meteorology in the early 1960s when the applied mathematician Edward Lorenz set up three linked first-order differential equations in a computer model of weather development. With certain parameters, the system proved so sensitive to the initial conditions that it was estimated that quite literally a butterfly flapping its wings in one part of the world would be sufficient to cause a major storm to emerge somewhere else. An arbitrarily small change could generate an entirely different history for the system. Obviously, acquisition and management of the precision and the amount of input data necessary for exact prediction pose an impractical problem, but the large scale of the atmospheric system is actually not the issue. The difficulty arises merely from multiplying pairs of the variables in two of the three coupled equations.[17] The heart of the matter is that the system's variables cannot be effectively isolated from each other or from their context; linearization is not possible, because dynamic interaction is one of the system's defining characteristics.

The question is whether, according to Clausewitz, wars are also nonlinear systems.

Is War Nonlinear for Clausewitz?

In Chapter 1 of Book One, Clausewitz engages the reader with three increasingly sophisticated definitions of war, each one of which is prominently marked by nonlinearity. The first definition is that war "is nothing but a duel

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of the damped, driven pendulum under more realistic conditions. See G.L. Baker and J.P. Gollub, *Chaotic Dynamics: An Introduction* (Cambridge: Cambridge University Press, 1990).

17. The Lorenz equations indicate the simplicity directly:

$$dx/dt = Py - Px, \qquad dy/dt = -xz + rx - y, \qquad dz/dt = xy - bz$$

where P, r, and b are adjustable parameters relating to fluid flow, thermal convection, etc. See the discussion in Celso Grebogi, Edward Ott, and James A. Yorke, "Chaos, Strange Attractors, and Fractal Basin Boundaries in Nonlinear Dynamics," *Science*, Vol. 238 (October 30, 1987), pp. 635–636; and a readable and more extended treatment in J.M.T. Thompson and H.B. Stewart, *Nonlinear Dynamics and Chaos: Geometrical Methods for Engineers and Scientists* (New York: Wiley, 1986), pp. 212–234.

[*Zweikampf*] on a larger scale. . . . *an act of force to compel our enemy to do our will*."[18] Because each opponent has the same intent, war is inherently an "interaction" (*Wechselwirkung*): it "is not the action of a living force upon a lifeless mass (total nonresistance would be no war at all) but always the collision of two living forces."[19] For Clausewitz, the interactive nature of war produces a system driven by psychological forces and characterized by positive feedback, leading "in theory" to limitless extremes of mutual exertion and efforts to get the better of one another. The course of a given war becomes thereby not the mere sequence of intentions and actions of each opponent, but the pattern or shape generated by mutually hostile intentions and simultaneously consequential actions. The contest is not the presence or actions of each opponent added together. It is the dynamic set of patterns made in the space between and around the contestants. This may not be immediately evident if we think of a duel with swords or with pistols. But it is obvious in a match between two wrestlers, which is how Clausewitz himself suggests we imagine the *Zweikampf* (literally "two-struggle") between opponents in war: the bodily positions and contortions that emerge in wrestling are often impossible to achieve without the counterforce and counterweight of an opponent.[20]

Clausewitz stresses that the logic of war in the abstract, with its limitless escalation of cost and effort, contradicts human experience; there are always constraints on human action. Only if war were some hermetically sealed phenomenon could its fundamental nature rage on unchecked. This would require that war (a) be an isolated and sudden act without prelude, (b) consist of a single decisive act or set of simultaneous ones, and (c) achieve a result perfectly complete in itself. But Clausewitz contends that an actual war never occurs without a context; that it always takes time to conduct, in a series of interactive steps; and that its results are never absolutely final—all of which impose restrictions on the analytically simple "pure theory" of war. Any specific war is subject to historical contingencies: thus he concludes that the theoretical basis for prediction of the course of a war dissolves from analytical certainties into numerical probabilities.[21] Wars, therefore, are not only characterized by feedback (a process distinctly involving nonlinearities), but inseparable from their contexts.

18. *On War*, p. 75. All emphases are in the original unless otherwise indicated.
19. Ibid., p. 77.
20. Ibid., p. 75.
21. Ibid., pp. 77–80.

The unique political situation is the context that bounds the system constituted by a given war. It must be considered carefully, Clausewitz argues, for "the same political object can elicit *differing* reactions from different peoples, and even from the same people at different times. . . . Between two peoples and two states there can be such tensions, such a mass of inflammable material, that the slightest quarrel can produce a wholly disproportionate effect—a real explosion."[22] Note the nonlinear image of combustion, and the view that the prevailing political conditions rather than the intended "political object" constitute the parameters that determine fundamental regimes of behavior in the system.[23] The emphasis on the changeable political context also contrasts sharply with the view held by many theorists (then and in our own time) that the parameters of war must be readily quantifiable military categories such as logistical factors, characteristics of weaponry, etc.[24]

Consideration of the political environment leads Clausewitz to generate his famous second definition of war as "merely the continuation of policy [*Politik*, which also means "politics" in German] by other means."[25] He claims that war is never autonomous, for it is always an instrument of policy. Yet the relationship is not static; it implies neither that the instrument is unchanging nor that the political goal or policy itself is immune to feedback effects. Using another image of explosion, he argues:

War is a pulsation of violence, variable in strength and therefore variable in the speed with which it explodes and discharges its energy. War moves on its goal with varying speeds; but it always lasts long enough for the influence to be exerted on the goal and for its own course to be changed in one way or another. . . . That, however, does not imply that the political aim is a tyrant. It must adapt itself to its chosen means, a process that can radically change it; yet the political aim remains the first consideration.[26]

The ends-means relationship clearly does not work in a linear fashion. The constant interplay is an interactive, feedback process that constitutes an

22. Ibid., p. 81.
23. See ibid., pp. 600–610, the tone of which is set on p. 602: "Still, as we have argued in the second chapter of Book One (purpose and means in war), the nature of the political aim, the scale of demands put forward by either side, and the total political situation of one's own side are all factors that in practice must decisively influence the conduct of war."
24. See, for example, the works of T.N. Dupuy, *Numbers, Prediction and War* (Indianapolis: Bobbs-Merrill, 1979); and Dupuy, *Understanding War: History and Theory of Combat* (New York: Paragon House, 1987).
25. *On War*, p. 87.
26. Ibid.

intrinsic feature of war. Clausewitz's conception is that the conduct of any war affects its character, and its altered character feeds back into the political ends that guide its conduct. War is, he says, a "true chameleon" that exhibits a different nature in every concrete instance.[27]

To reach an understanding of the character of war in general is a purpose of theory and, to describe how that theory functions, Clausewitz resorts to a third definition that he elucidates in terms of a striking metaphor of nonlinearity. In the last section of Chapter 1, Book One, he claims that war is "a remarkable trinity" (*eine wunderliche Dreifaltigkeit*) composed of (a) the blind natural force of violence, hatred, and enmity among the masses of people; (b) chance and probability, faced or generated by the commander and his army; and (c) war's rational subordination to the policy of the government.[28] Clausewitz compares these three tendencies to three varying legal codes interacting with each other (the complexity of which would have been obvious to anyone who had lived under the tangled web of superimposed legal systems in the German area before, during, and after the upheavals of the Napoleonic years). Then he concludes with a visual metaphor: "Our task therefore is to develop a theory that maintains a balance between these three tendencies, like an object suspended between three magnets."[29] What better image could he have conjured to convey his insight into the profoundly interactive nature of war than this emblem of contemporary nonlinear science?[30]

Although the passage is usually taken to mean only that we should not overemphasize any one element in the trinity, Clausewitz's metaphor also implicitly confronts us with the chaos inherent in a nonlinear system sensitive to initial conditions. The demonstration usually starts with a magnet pendulum hanging over one magnet; when the pendulum is pulled aside and let go, it comes to rest quickly. Positioned over two equally powerful magnets, the pendulum swings toward first one, then the other, and still settles into a rest position as it is captured by one of the points of attraction. But when the pendulum is released over three equidistant and equally powerful magnets, it moves irresolutely to and fro as it darts among the competing points of attraction, sometimes kicking out high enough to acquire added

27. Ibid., p. 89.
28. Ibid.
29. Ibid.
30. See, for example, the PBS "Nova" program entitled "The Strange New Science of Chaos," which aired in January 1989.

momentum that allows it to keep gyrating in a startlingly long and intricate pattern. Eventually, the energy dissipates under the influence of friction in the suspension mountings and the air, bringing the pendulum's movement asymptotically to rest. The probability is vanishingly small that an attempt to repeat the process would produce exactly the same pattern. Even such a simple system is complex enough for the details of the trajectory of any actual "run" to be, effectively, irreproducible.

My claim here is not that Clausewitz somehow anticipated today's "chaos theory," but that he perceived and articulated the nature of war as an energy-consuming phenomenon involving competing and interactive factors, attention to which reveals a messy mix of order and unpredictability. His final metaphor of Chapter 1, Book One captures this understanding perfectly. The pendulum and magnets system is orderly, because it is a deterministic system that obeys Newton's laws of motion; in the "pure theory" (with an idealized frictionless pendulum), we only need to know the relevant quantities accurately enough to know its future. But in the real world, "a world like this" in Maxwell's phrase, it is not possible to measure the relevant initial conditions (such as position) accurately enough to replicate them in order to get the same pattern a second time, because all physical measurements are approximations limited by the instrument and standard of measurement. And what is needed is infinitely fine precision, for an immeasurably small change in the initial conditions can produce a significantly different pattern. Nor is it possible to isolate the system from all possible influences around it, and that environment will have changed since the measurements were taken. Anticipation of the overall kind of pattern is possible, but quantitative predictability of the actual trajectory is lost.

There are a number of interconnected reasons for the pendulum-and-magnets picture to be emblematic for Clausewitz, and all of them go to the heart of the problem of understanding what he meant by a "theory" of war. First of all, the image is *not* that of any kind of Euclidean triangle or triad, despite its understanding as such by many readers. Given his attacks on the formulation of rigidly "geometric" principles of war by some of his contemporaries, such an image would have been highly inapt.[31] Clausewitz's message is not that there are three passive points, but three interactive points of attraction that are simultaneously pulling the object in different directions

31. See, e.g., *On War*, pp. 214–215.

and forming complex interactions with each other. In fact, even the standard translation given above is a bit too static, for the German original conveys a sense of on-going motion: *"Die Aufgabe ist also, dass sich die Theorie zwischen diesen drei Tendenzen wie zwischen drei Anziehungspunkten schwebend erhalte."*[32] Literally: "The task is therefore that the theory would maintain itself floating among these three tendencies as among three points of attraction." The connotations of *schweben* involve lighter-than-air, sensitive motion; a balloon or a ballerina *"schwebt."* The image is no more static than that of the wrestlers. The nature of war should not be conceived as a stationary point among the members of the trinity, but as a complex trajectory traced among them.

Secondly, Clausewitz's employment of magnetism is a typical resort to "high-tech" imagery. The relationship of magnetism to electricity was just beginning to be clarified in a way that made it a cutting-edge concept for its time. It is quite possible that he actually observed a demonstration of a pendulum and three magnets as envisioned in the metaphor, for he was a man of considerable scientific literacy.[33] His famous incorporation of the notion of "friction," also a high-technology concept for his day, is another example of this characteristic of his thought.

Thirdly, and perhaps most importantly, the metaphor offers us insight into a mind realistically willing to abandon the search for simplicity and analytical certainty where they are not obtainable. The use of this image displays an intuitive grasp of dynamic processes that can be isolated neither from their context nor from chance, and are thus characterized by inherent complexities and probabilities. It encodes Clausewitz's sense of war in a realistic dynamical system, not an idealized analytical abstraction.

The image of the interactive "remarkable trinity" is thus a densely rich metaphor, but is it only a literary device? A stylistic trick? Or is it fundamental to understanding Clausewitz? Raymond Aron thought it representative of a major shift from dualism to a form of triadism that constituted the final state of Clausewitz's thought.[34] Michael Howard ended his excellent short biog-

32. *Vom Kriege*, p. 213.
33. The experiment requires only simple apparatus. During the time Clausewitz was composing *On War* he attended the lectures of physicist Paul Erman at the *Kriegsschule* for an entire year without missing a single lecture. Erman was publishing on the new field of electricity, and emphasized precision of observation over the then-fashionable intuitive approach to nature. Erman's son was also studying physics in these same years with a special interest in magnetism. See Paret, *Clausewitz*, p. 310.
34. Aron, *Clausewitz*, p. 2.

raphy with this trinity, and suggested that it formed both Clausewitz's conclusion and a good starting place for any contemporary strategic thinker.[35]

But the pendulum-and-magnets metaphor reveals more than Clausewitz's concluding thought. If this metaphor can bear the burden of my contention, *On War* ought to be filled with insights intended to identify and cope with nonlinearities. Clausewitz ought to display a deep and abiding concern for unpredictability and complexity, and consequently to search for ways to express the importance of such matters as context, interaction, effects disproportionate to their causes, sensitivity to initial conditions, time-dependent evolutionary processes, and the serious limitations of linear analysis. If he does, we will have a viable explanation for the compelling nature of *On War* and many of its difficulties for readers, because the intuition needed to investigate nonlinear dynamical systems runs counter to much of what has constituted scientific theory since the time of Galileo and Newton.

How Does Nonlinearity Manifest Itself in On War?

Clausewitz's emphasis on unpredictability is a key manifestation of the role that nonlinearity plays in his work. This emphasis links widely recognized, fundamental, enduring elements of *On War.* A look at what Clausewitz says about "interaction," "friction," and "chance" may allow us to explore his understanding of the nonlinear nature of war.

UNPREDICTABILITY FROM INTERACTION

It may seem obvious that war is an interactive process, yet Clausewitz was at great pains to emphasize the point and to assail his contemporaries for ignoring this basic aspect of reality. That war is profoundly interactive is underscored by each of the definitions of the phenomenon in Chapter 1, Book One. The question is whether Clausewitz related this concept to the unpredictability that characterizes nonlinear systems. The answer is unequivocally yes. In Chapter 3 of Book Two, Clausewitz considers whether the study of war is an art or a science. He concludes that it is neither: "The essential difference is that war is not an exercise of the will directed at inanimate matter, as is the case with the mechanical arts, or at matter which is animate but passive and yielding, as is the case with the human mind and

35. Michael Howard, *Clausewitz* (Oxford: Oxford University Press, 1983), p. 73.

emotions in the fine arts. In war, the will is directed at an animate object that *reacts*."[36] A military action produces not a single reaction, but dynamic interactions and anticipations that pose a fundamental problem for any theory. Such patterns can be theorized only in qualitative and general terms, not in the specific detail needed for prediction: "The second attribute of military action is that it must expect positive reactions, and the process of interaction that results. Here we are not concerned with the problem of calculating such reactions—that is really part of the already mentioned problem of calculating psychological forces—but rather with the fact that the very nature of interaction is bound to make it unpredictable."[37] Clausewitz thus understood an essential feature of nonlinearity and applied its consequences in his understanding of war: the core cause of analytical unpredictability in war is the *very nature of interaction* itself.

Interaction occurs not just between adversaries, but also in processes that occur on each side as a consequence of the contest. This is demonstrated in Book Four, as Clausewitz discusses the differing effects of victory or defeat on the battlefield. The consequences are often disproportionately felt:

> As we have already mentioned in Chapter Seven, the scale of a victory does not increase simply at a rate commensurate with the increase in size of the defeated armies, but progressively. The outcome of a major battle has a greater psychological effect on the loser than the winner. This, in turn, gives rise to additional loss of material strength [through abandonment of weapons in a retreat or desertions from the army], which is echoed in loss of morale; the two become mutually interactive as each enhances and intensifies the other.[38]

Such an amplifying feedback process is as nonlinear as those in any field, from turbulence in the atmosphere to the optics of a laser.

Clausewitz's concern for interaction permeates *On War*, and it has certainly commanded the attention of commentators. The crucial importance of interaction is usually phrased in terms of Clausewitz's "dialectical" method, although his non-Marxist adherents have usually been at pains to distinguish the dialectic in Clausewitz's work from Hegel's method.[39] Aron, in particular,

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36. Clausewitz, *On War*, p. 149.
37. Ibid., p. 139.
38. Ibid., p. 253.
39. See, e.g., Aron, *Clausewitz*, pp. 225–228; Howard, *Clausewitz*, p. 34; and Paret, *Clausewitz*, p. 84, note 13. Engels and Lenin, however, praised *On War* largely because they read the Hegelian dialectic into it; see Martin Kitchen, "The Political History of Clausewitz," *Journal of Strategic Studies*, Vol. 11, No. 1 (March 1988), pp. 27–50.

devoted an entire section of his two-volume study to Clausewitz's dialectic. He argued that the categories termed "moral-physical," "means-ends" and "defense-attack" formed "the three conceptual pairs around which the system develops."[40] He recognized better than many commentators that Clausewitz does not demand binary opposites and is willing to live with ambiguity: "[Clausewitz] explicitly recognizes that the clear opposition of two poles risks becoming confused in the intermediate zones. . . . In reality, the distinctions, conceptually clear-cut, give way to doubtful cases or even to mixed cases. Clausewitz does not see real objections in these remarks: the distinction, conceptually valid, does not preclude uncertain boundaries in reality."[41] Aron's use of the word "risks" (*risque*), however, perhaps betrayed discomfort with the analytical ambiguity that comes with taking interaction seriously.

Clausewitz himself displays no unease with ambiguity in the passages under discussion. He appears, on the contrary, to relish the complexity of the relationship between tactics and strategy:

> The art of war in the narrower sense must now in its turn be broken down into tactics and strategy. The first is concerned with the form of the individual engagement, the second with its use. . . . Admittedly only the rankest pedant would expect theoretical distinctions to show direct results on the battlefield. . . . Tactics and strategy are two activities that permeate one another in time and space but are nevertheless essentially different. Their inherent laws and mutual relationship cannot be understood without a total comprehension of both.[42]

The purpose of theory is to untangle confusion by creating distinctions, but to do so in order to understand the whole better, not for the sake of pedantic analytical compartmentalization.

What interests Clausewitz, I argue, is not so much either pole in any of his analytical pairs, nor even either opponent in war, but the tangled dynamics occurring between them. This is consistent with the wrestlers' image of the *Zweikampf*. Many theorists tend, for the sake of analytical simplicity, to force war into the model sequence of move-countermove. But any good commander will seek to take advantage of the disproportionate effects or unpredictable situations generated by nonlinearities. Furthermore, war is not

40. Aron, *Clausewitz*, p. 90.
41. Ibid., pp. 98–99; *Penser la guerre*, Vol. 1, p. 166.
42. *On War*, p. 132.

chess; one's opponent is not always playing by the same rules, and is often, in the effort to win, attempting to *change* what rules there are. This is a major reason that how a war is conducted can and does change its character, and that any war is (in Maxwell's sense) structurally unstable.

Capturing the essence of this "true chameleon" is Clausewitz's aim. He is therefore willing to accept uncertainty and complex interaction as major factors in order to cope with what is happening along the hazy boundaries where the opposing forces in war, or contending categories in theory, are actually engaged. Facing up to the intrinsic presence of chance, complexity, and ambiguity in war is imperative. For Clausewitz, this is preferable to the risk of being blind-sided by the strictures of a theory artificially imposed on the messiness of reality in the name of clarity.

UNPREDICTABILITY FROM FRICTION

A key element of reality for Clausewitz is the ubiquity of "friction," the "only concept that more or less corresponds to the factors that distinguish real war from war on paper."[43] This concept is usually interpreted as a form of "Murphy's Law": whatever can go wrong, will, and at the worst possible moment. That interpretation is not bad as far as it goes, but its presentation is usually skewed. The implication is that things go right until some exogenous factor ruins the situation. But for Clausewitz friction is neither extrinsic nor abnormal:

> Everything in war is simple, but the simplest thing is difficult. The difficulties accumulate and end by producing a kind of friction that is inconceivable unless one has experienced war. . . . Countless minor incidents—the kind you can never really foresee—combine to lower the general level of performance, so that one always falls far short of the intended goal. . . . The military machine—the army and everything related to it—is basically very simple and therefore seems easy to manage. But we should bear in mind that none of its components is of one piece: each part is composed of individuals, . . . the least important of whom may chance to delay things or somehow make them go wrong. . . . This tremendous friction, which cannot, as in mechanics, be reduced to a few points, is everywhere in contact with chance, and brings about effects that cannot be measured, just because they are largely due to chance.[44]

43. Ibid., p. 119.
44. Ibid., pp. 119–120.

The concept of friction is not just a statement that in war things always deviate from plan, but a sophisticated sense of *why* they do so. The analytical world, epitomized by the "frictionless pendulum" or the "perfectly spherical billiard ball on a frictionless surface" or "low-amplitude vibrations" so common in elementary physics, is one of linear rules and predictable effects. The real world and real war are characterized by the unforeseeable effects generated through the nonlinearity of interaction.

"Friction" as used by Clausewitz entails two different but related notions that demonstrate the depth of his powers of observation and intuition. One meaning is the physical sense of resistance embodied in the word itself, which in Clausewitz's time was being related to heat in ways that would lead ultimately to the Second Law of Thermodynamics and the concept of entropy.[45] Friction is a nonlinear feedback effect that leads to the heat dissipation of energy in a system. The dissipation is a form of increasing degradation toward randomness, the essence of entropy. Even in peacetime, the degradation of performance in an army is a continual problem. In war, the difficulties are amplified. Military friction is counteracted by training, discipline, inspections, regulations, orders, and other means, not the least of which, according to Clausewitz, is the "iron will" of the commander.[46] New energy and effort are sucked into the open system, yet things still never go as planned; dissipation is endemic due to the interactive nature of the parts of the system.

The second meaning of "friction" is the information theory sense of what we have recently come to call "noise" in the system. Entropy and information have some interesting formal similarities, because both can be thought of as measuring the possibilities for the behavior of systems. According to information theory, the more possibilities a system embodies, the more "information" it contains. Constraints on those possibilities are needed to extract signals from noise. Clausewitz understands that plans and commands are signals that inevitably get garbled amid noise in the process of communicating them down and through the ranks even in peacetime, much less under

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45. See D.S.L. Cardwell, *From Watt to Clausius: The Rise of Thermodynamics in the Early Industrial Age* (London: Heinemann, 1971), esp. pp. 186–294. On the relationships of nonlinearity and entropy, see the works of Ilya Prigogine, esp., with Isabelle Stengers, *Order Out of Chaos* (New York: Bantam, 1984); and Arthur Peacocke, "Thermodynamics and Life," *Zygon*, Vol. 19, No. 4 (December 1984), pp. 395–468.
46. *On War*, p. 119. See also p. 153: "Routine, apart from its sheer inevitability, also contains one positive advantage. Constant practice leads to *brisk, precise,* and *reliable* leadership, reducing natural friction and easing the working of the machine."

the effects of physical exertion and danger in combat. His well-known discussion of the difficulty in obtaining accurate intelligence presents the problem from the inverse perspective, as noise permeates the generation and transmission of information rising upward through the ranks.[47] From this perspective, his famous metaphor of the "fog" of war is not so much about a dearth of information as how distortion and overload of information produce uncertainty as to the actual state of affairs.

Clausewitz's basic intuition here is that organizations are always slower and more inflexible than the natural events they are intended to control. Seen in this light, training, regulations, procedures, and so on are redundancies that enhance the probability of signal recognition through the noise. On the basis of linear assumptions, one expects major obstacles to produce proportionately serious errors in responding to the message. Clausewitz emphasizes, however, the disproportionately large role of the *least* important of individuals and of minor, unforeseeable incidents. "Friction" conveys Clausewitz's sense of how unnoticeably small causes can become amplified in war until they produce macroeffects, and that one can never anticipate those effects.[48] The issue is not just that "for want of a nail the shoe was lost . . . ," but that one can never calculate in advance *which* nail on which shoe will turn out to be critical. Due to our ignorance of the exact initial conditions, the cause of a given effect must, for all intents and purposes, often be treated as unavoidable chance.

UNPREDICTABILITY FROM CHANCE

How are we to understand "chance," which Clausewitz finds pervasive? It is one of the three points of attraction in his definition of war as a remarkable trinity, and he emphasizes that "no other human activity is so continuously or universally bound up with chance" as is war.[49] It is associated also with the fog of uncertainty in war, which obscures or distorts most of the factors on which action is based. Yet he nowhere provides a succinct definition of chance.

47. Ibid., pp. 101 and 117–118.
48. On how simple nonlinear systems exhibiting chaotic behavior can similarly be viewed as "information pumps" that amplify immeasurably small differences, see Robert Shaw, "Strange Attractors, Chaotic Behavior, and Information Flow," *Zeitschrift der Naturforschung*, Vol. 36a (1981), pp. 80–112.
49. *On War*, p. 85.

The connection between chance and uncertainty provides a means of understanding both, if we draw upon the insights of the late nineteenth-century mathematician Henri Poincaré, whose understanding of the matter was powerful enough that he is a frequently cited source in nonlinear science today. Poincaré argued that chance comes in three guises: a statistically random phenomenon; the amplification of a microcause; or a function of our analytical blindness. He described the first as the familiar form of chance that can arise where permutations of small causes are extremely numerous or where the number of variables is quite large. This form of chance can be calculated by statistical methods. The very large number of interactions produces a disorganization sufficient to result in a symmetrical (i.e., Gaussian or bell curve) probability distribution. Nothing significant is left of the initial conditions, and the history of the system no longer matters.[50] It is possible that Clausewitz was aware of this general line of reasoning. As with magnetism and friction, important developments in probability theory were occurring in Clausewitz's time, and we know that he read intensely in mathematical treatises.[51]

Of course *On War* does not present this statistically tractable form of chance in exactly the way Poincaré explained it later, although commentators have noted that Clausewitz often refers to the role of probability in a commander's calculations.[52] In Chapter 1, Book One, he notes that "absolute, so-called mathematical factors" are not sound bases for such calculations due to the "interplay of possibilities, probabilities, good luck and bad" that are endemic in war. The "games of chance" most amenable to statistical treatment are those like dice and coin tossing, but when Clausewitz compares war to a

50. Henri Poincaré, "Chance," in *Science and Method*, reprinted in *The Foundations of Science*, trans. George Bruce Halsted [1913] (Washington, D.C.: University Press of America, 1982), pp. 400–406.
51. On Clausewitz's interest in mathematics, see Paret, *Clausewitz*, pp. 127 and 150; and Clausewitz to his future wife, February 28, 1807, in K. Linnebach, ed., *Karl und Marie von Clausewitz: Ein Lebensbild in Briefen und Tagebuchblättern* (Berlin: Martin Warneck, 1925), p. 94. On the history of probability theory in the period, see Lorraine Daston, *Classical Probability in the Enlightenment* (Princeton: Princeton University Press, 1988), esp. pp. 226–295.
52. Katherine Herbig has remarked that analysis of statistical probability depends on large numbers of events to be valid, while Clausewitz stressed the unique and distinctive events in war. Raymond Aron has noted the emphasis that Clausewitz placed on an intuitive rather than calculative grasp of probabilities. However, the relevance of Poincaré here relates to the generation of statistical chance rather than how to cope with it. Katherine Herbig, "Chance and Uncertainty in *On War*," in Michael I. Handel, ed., *Clausewitz and Modern Strategy* (London: Frank Cass, 1986), p. 107 (originally published in *Journal of Strategic Studies*, Vol. 9, No. 2/3 [June/September 1986]); Aron, *Clausewitz*, p. 185.

gamble, he does not use either. For him, "in the whole range of human activities, war most closely resembles a game of cards."[53] This analogy suggests not only the ability to calculate probabilities, but knowledge of human psychology in "reading" the other players, sensing when to take risks, and so on. Clausewitz certainly understands that the number of variables in war can be enormous, and that a rather special aptitude is needed to cope with the chance and complexity involved:

Circumstances vary so enormously in war, and are so indefinable, that a vast array of factors has to be appreciated—mostly in the light of probabilities [*Wahrscheinlichkeitsgesetze*] alone. The man responsible for evaluating the whole must bring to his task the quality of intuition that perceives the truth at every point. Otherwise a chaos of opinions and considerations would arise, and fatally entangle judgment. Bonaparte rightly said in this connection that many of the decisions faced by the commander-in-chief resemble mathematical problems worthy of the gifts of a *Newton* or an *Euler*.[54]

Since a mathematician of the likes of Newton or Euler is unlikely to be making military decisions, those in command have to rely on judgment rooted in intuition, common sense, and experience. Statistical laws of probability alone will never suffice, because moral factors always enter into real war, and it is possible for the results of any given action to defy the odds. This is one of the most important facts that experience indeed provides.[55]

A second form of chance described by Poincaré is deeply embedded in *On War*, but commentators have not usually distinguished its nature from that of the first.[56] In contrast to the statistical form characterized above, this type of chance—amplification of a microcause—is inherent in the system itself. It arises from the fact that in certain deterministic systems small causes can have disproportionately large effects at some later time. Because the history of the system matters, the initial conditions remain significant. In a passage often cited by researchers working on nonlinear dynamics, Poincaré explained:

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53. *On War*, p. 86.
54. Ibid., p. 112.
55. Ibid., pp. 136–140.
56. An exception is Barry D. Watts, who has explored Clausewitz's concept of friction from this perspective. See Watts, *The Foundations of U.S. Air Doctrine: The Problem of Friction in War* (Maxwell A.F.B., Ala.: Air University Press, 1984); and James G. Roche and Barry D. Watts, "Choosing Analytic Measures," *Journal of Strategic Studies*, Vol. 14, No. 2 (June 1991), pp. 191–194. See also Bassford's manuscript (note 2 above), chap. 2.

> A very slight cause, which escapes us, determines a considerable effect which we can not help seeing, and then we say this effect is due to chance. If we could know exactly the laws of nature and the situation of the universe at the initial instant, we should be able to predict exactly the situation of this same universe at a subsequent instant. But even when the natural laws should have no further secret for us, we could know the initial situation only *approximately.* If that permits us to foresee the subsequent situation *with the same degree of approximation,* this is all we require, [and] we say the phenomenon has been predicted, that it is ruled by laws. But this is not always the case; it may happen that slight differences in the initial conditions produce very great differences in the final phenomenon; a slight error in the former would make an enormous error in the latter. Prediction becomes impossible and we have the fortuitous phenomenon.[57]

Poincaré thus linked the crucial importance of the initial conditions to the idea that in the real world the precision of our information concerning causes is always limited. This is a root explanation for unpredictability in those nonlinear phenomena that exhibit chaotic regimes of behavior.

This is exactly how Clausewitz perceives the role of chance in relation to friction in real war. Unnoticeably small causes can be disproportionately amplified. Decisive results can often rest on particular factors that are "details known only to those who were on the spot."[58] Attempts to reconstruct cause and effect always face the lack of precise information: "Nowhere in life is this so common as in war, where the facts are seldom fully known and the underlying motives even less so. They may be intentionally concealed by those in command, or, if they happen to be transitory and accidental, history may not have recorded them at all."[59] We can never recover the precise initial conditions even of known developments in past wars, much less developments in current wars distorted by the fog of uncertainty. Interactions at every scale within armies and between adversaries amplify microcauses and produce unexpected macroeffects. Since interaction is intrinsic to the nature of war, it cannot be eliminated. The precise knowledge needed to anticipate the effects of interaction is unattainable. Unpredictability in war due to this second form of chance is thus unavoidable.

There is yet a third type of chance discussed by Poincaré that is prominently displayed in Clausewitz's work. Poincaré argued that this kind is a result of our inability to see the universe as an interconnected whole: "Our

57. Poincaré, "Chance," pp. 397–398.
58. *On War,* p. 595.
59. Ibid., p. 156.

weakness forbids our considering the entire universe and makes us cut it up into slices. We try to do this as little artificially as possible. And yet it happens from time to time that two of these slices react upon each other. The effects of this mutual action then seem to us to be due to chance."[60] Thus the drive to comprehend the world through analysis, the effort to partition off pieces of the universe to make them amenable to study, opens the possibility of being blind-sided by the very artificiality of the partitioning practice. This form of chance is a particularly acute problem when our intuition is guided by linear precepts.

Clausewitz has a profound sense of how our understanding of phenomena around us is truncated by the bounds we place on them for our analytical convenience. The assertion from *On War* quoted above, that "circumstances vary so enormously in war, and are so indefinable," makes this point explicitly in the German original. A literal translation refers to the "diversity and indistinct boundary of all relationships" ("*die Mannigfaltigkeit und die unbestimmte Grenze aller Beziehungen*") with which a commander must cope. Clausewitz repeatedly stresses the failure by theorists, such as his contemporaries Jomini and Bülow, to obtain effective principles because they insist on isolating individual factors or aspects of the problems presented in war. One indictment is particularly well known:

Efforts were therefore made to equip the conduct of war with principles, rules, or even systems. This did present a positive goal, but people failed to take adequate account of the endless complexities involved. As we have seen, the conduct of war branches out in almost all directions and has no definite limits; while any system, any model, has the finite nature of a synthesis [in the sense of synthetic or man-made]. An irreconcilable conflict exists between this type of theory and actual practice. . . . [These attempts] aim at fixed values; but in war everything is uncertain, and calculations have to be made with variable quantities. They direct the inquiry exclusively toward physical quantities, whereas all military action is entwined with psychological forces and effects. They consider only unilateral action, whereas war consists of a continuous interaction of opposites.[61]

For Clausewitz, the generation of any system of principles for the conduct of war is a desirable goal but an unattainable one. Such an act of synthesis is indeed attractive, because it becomes so easy to forget the filters we have imposed on our view of the phenomenon.

60. Poincaré, "Chance," p. 403.
61. *On War*, pp. 134 and 136.

But his concerns, like those of many scientists wrestling with nonlinear phenomena today, are open systems which cannot be isolated from their environments even in theory, which are characterized by numerous levels of feedback effects, and which need to be grasped realistically as an interactive whole. Traditional analysis that aimed at breaking the system into simpler parts fails now just as surely as it did in Clausewitz's time, and for the same reasons. As Clausewitz writes of critical analysis and proof:

> It is bound to be easy if one restricts oneself to the most immediate aims and effects. This may be done quite arbitrarily if one isolates the matter from its setting and studies it only under those conditions. But in war, as in life generally, all parts of the whole are interconnected and thus the effects produced, however small their cause, must influence all subsequent military operations and modify their final outcome to some degree, however slight. In the same way, every means must influence even the ultimate purpose.[62]

Interconnectedness and context, interaction, chance, complexity, indistinct boundaries, feedback effects and so on, all leading to analytical unpredictability—it is no wonder that *On War* has confused and disappointed those looking for a theory of war modeled on the success of Newtonian mechanics.

The Role of Linearity

It is important to emphasize that Clausewitz does not hold the view that linearity is nowhere valid in war. As much as any military professional, he clearly wants to find or generate conditions under which outcomes may be guaranteed. His attention to situations characterized by direct, sequential cause-effect relationships or proportionality makes Clausewitz's understanding of the consequences of nonlinearity more supple—and credible—than if he ignored linearities entirely. But he is aware that linear relations and the predictability they offer are the exceptions in the real world, so he usually surrounds a linear effect with a discussion of the constraints needed to achieve it.

For Clausewitz, the parameters that make linear approximations possible are the political-military analogs of shallow waves or low-amplitude vibrations. In Chapter 1, Book One, for instance, he notes that political objectives come to the fore as the limitations of the real world dampen the theoretical tendency of pure war to be driven to absolute extremes: "The smaller the

62. Ibid., p. 158.

penalty you demand from your opponent, the less you can expect him to try to deny it to you; the smaller the effort he makes, the less you need make yourself."[63] This offers an example of linearity. Yet Clausewitz in the next paragraph restricts such a relationship:

> The political object—the original motive for the war—will thus determine both the military objective to be reached and the amount of effort it requires. The political object cannot, however, *in itself* provide the standard of measurement. Since we are dealing with realities, not with abstractions, it can do so only in the context of the two states at war. The same political object can elicit *differing* reactions from different peoples, and even from the same people at different times. [Here follows the nonlinear image of combustion noted on p. 68 above]. . . . The less involved the population and the less serious the strains within states and between them, the more political requirements in themselves will dominate and tend to be decisive. Situations can thus exist in which the political object will almost be the sole determinant.[64]

The context in which a war begins thus sets an initial range of possibilities for the relationship between political objective and military exertion. Situations "can" exist in which a single variable "almost" solely determines the outcome. But this requires that one of the magnetic attractions in the "remarkable trinity"—the primordial passions of the people—be diminished so greatly as to be effectively removed.

The embedding of linearity in a general environment of nonlinearity is thoroughly characteristic of *On War.* This awareness of the full range of the system's behavior prevails not only when Clausewitz considers the outbreak of war, but also when he assesses the impact of a single battle in a war. In a chapter where he discusses the disproportionate, nonlinear effects of a victory, Clausewitz relates other processes in clearly linear terms: "Our argument is that the effects of victory that we have described will always be present; that they increase in proportion to the scale of the victory; and they increase the more the battle is a major one."[65] Yet he encompasses this remark within assertions that the effects of victories still depend very much on the context, including the character of the victorious commander, whether moral forces will be aroused on the other side that "would otherwise have remained

63. Ibid., p. 81.
64. Ibid.
65. Ibid., p. 256.

dormant," and so on.[66] It is even possible, therefore, for a victory to have the entirely unexpected effect of rallying the losing side.

Seen from this perspective, the best-known and most popular of the linearities identified by Clausewitz—the offensive thrust at the enemy's "center of gravity"—looks quite different than it is usually depicted. Defeat of the enemy, he holds, involves "chances and incidents so minute as to figure in histories simply as anecdotes," but out of the dominant characteristics of each belligerent "a center of gravity [*Schwerpunkt*] develops, the hub of all power and movement, on which everything depends."[67] Practicing soldiers may warm to the idea of focusing one's efforts on the most critical concentration of the enemy's fighting forces in order to strike the most telling blow. But they balk when Clausewitz goes on to suggest that under specific circumstances the center of gravity could be a city, or a community of interest among allies, or the personality of a leader or even public opinion.[68] Furthermore, he urges an awareness of the restraints imposed by considerations of economy of force: any excess of force is worse than just a waste, for it means unnecessary weakness elsewhere.[69] Even more unsettling for some readers, he says that he is only describing what has been done in the past and wants "to reiterate emphatically that here, as elsewhere, our definitions are aimed only at the centers of certain concepts; we neither wish [to] nor can give them sharp outlines."[70] Even this most Newtonian-sounding analogy of a "center of gravity" becomes swamped in qualifications and caveats intended to convey the complexity of real war.

No wonder that, in an effort to cut through the maddening maze of qualification, students of *On War* tend to linearize and simplify what is said. The upshot is often an implicit or even explicit claim that, if Clausewitz were only less confused and understood his own concepts better, he would sound like Jomini. In a recent example, the military authors of an article rehearsed the above passages, but were clearly relieved when they could finally report that Clausewitz goes on to say that no matter what the center of gravity may be, "defeat of the enemy fighting force remains the best way to begin." For

66. Ibid., pp. 256–257. This outcome is certainly exceptional, but hardly unknown: the German victory at Dunkirk and the Japanese victory at Pearl Harbor provide obvious twentieth-century examples.
67. Ibid., pp. 595–596.
68. Ibid., p. 596.
69. Ibid., p. 486.
70. Ibid.

them, this strategy retrieved the analogy from the region "beyond its applicability" in the psychological realm and "reestablishes the analogy of the center of gravity in its proper physical domain."[71] They then immediately proceeded to contrast Clausewitz's terminology with that of Jomini, whose crisply stated maxims about the "decisive point" were held to be much more clear. But the continual twisting about that fills *On War* is not just a case of Clausewitz's being ponderous and wordy. Instead, the apparently irresolute to and fro of his prose conforms fully to his metaphor of theory floating among competing points of attraction.

Clausewitz's partisans, who agree with him that a theory of war cannot be axiomatic, nevertheless have also often labored under the implicit imperative that a good theory must conform to a linear intuition. Examples can be found even among the most articulate and sensitive interpreters of his work. Two essays by Bernard Brodie, long an influential member of the American defense analysis community, were included by Howard and Paret in their 1976 translation of *On War.* It is striking that even Brodie sometimes attempted to legitimate Clausewitz's ideas by linearizing them. For example, when Clausewitz states that the events of a war can change policy, according to Brodie Clausewitz cannot really mean this, "for to admit even a high probability of such a feedback effect would be to destroy his basic contention that war is the instrument of policy and not the reverse." But Clausewitz not only admits this feedback effect, he specifically *underscores* it in the passage under discussion, and it is typical of his conception of war.[72] The relationship between policy and war cannot be that of a discrete independent variable and a discrete dependent variable, for it is impossible to isolate the ends from the means used to pursue them.

Once identified as such, Clausewitz's perception that war is a profoundly nonlinear phenomenon seems so obvious that the natural question is why this has not been clearly understood all along. The answer is that what is

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71. James J. Schneider and Lawrence L. Izzo, "Clausewitz's Elusive Center of Gravity," *Parameters,* Vol. 17, No. 3 (September 1987), p. 50.
72. Brodie, "A Guide to the Reading of *On War,*" *On War,* p. 647. The passage in Clausewitz that Brodie discusses reads: "One point is purposely ignored for the moment—the difference that the *positive* or *negative* character of the political ends is bound to produce in practice. As we shall see, the difference is important, but at this stage we must take a broader view because the original political objects can greatly alter during the course of the war and may finally change entirely *since they are influenced by events and their probable consequences." On War,* p. 92. For a statement by Clausewitz that the means always affect the ends, see *On War,* p. 158. On Brodie's overall appreciation of Clausewitz, see Barry H. Steiner, *Bernard Brodie and the Foundations of American Nuclear Strategy* (Lawrence, Kan.: University Press of Kansas, 1991), esp. pp. 210–225.

meant by "theory" has been profoundly linear, to some extent already in Clausewitz's time and increasingly so since. Simplicity achieved by idealized isolation of systems and of variables within systems, deterministic laws, clearly delineated boundaries, linear causal trains, and other tools with which to forge analytical prediction have become the hallmarks of good theory. By using such techniques, rooted in the parsimonious and deductive power of logic, we have searched for—and therefore overwhelmingly found—static equilibria, consistent explanations, periodic regularities, and the beauty of symmetry.

Of course, as Ian Stewart noted, all of this comes at a price, namely the restriction of our vision to low-amplitude vibrations, shallow waves, small perturbations, and their analogs. We have trained our imaginations to be fundamentally linear. We have been able to devise analytical equations that offer prediction, but only by implicitly requiring that the system not be allowed to change too much in the meantime. We artificially require that our systems be stable in the sense expressed by Maxwell, and then are surprised by the manifest instability we encounter in the real world. A scientist at Los Alamos National Laboratory has summed up our situation: "That a system governed by deterministic laws can exhibit effectively random behavior runs counter to our normal intuition. Perhaps it is because intuition is inherently 'linear'; indeed, deterministic chaos *cannot* occur in linear systems."[73]

The realization that we have been wearing analytical blinders is becoming increasingly widespread. Looking to the future relationship between basic and applied physics, a National Research Council panel lamented the general lack of an adequate intuition: "Our inheritance of experience with simple systems is strikingly empty of images, intuitions, and methods for dealing with nonlinear problems of complexity. We know almost nothing of the workings and accustomed regularities of such systems. And to proceed we must come to know them intimately."[74] Working over one hundred and fifty years ago with the requisite intuition, Clausewitz had no precise and commonly accepted vocabulary with which to express his insights into nonlinear systems. He thus wrestled for years with formulations of his insights, unwilling to abandon realism for idealization.

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73. Campbell, "Nonlinear Science," p. 231.
74. U.S. National Research Council, Physics Survey Committee, *Scientific Interfaces and Technological Applications (Physics through the 1990's)* (Washington, D.C.: National Academy Press, 1986), p. 132.

It seems clear that in *On War* Clausewitz also senses that any prescriptive theory entails linearization, which is why he holds a dim view of such theory in the real world in which war actually occurs. Only an idealized "pure theory" of war could be predictive with universal prescriptions. In our world of probabilities rather than axiomatic certainties, by contrast, any useful theory must instead be heuristic, for each war is "a series of actions obeying its own peculiar laws."[75] The purpose of theory in our world is to expand the range of personal experience that is the best aid to judgment in war: it is "meant to educate the mind of the future commander, or, more accurately, to guide him in his self-education."[76] Since war evolves through time, the best techniques available are historical, which offer an indication only of what is possible, not of what is necessary, in the future.

Clausewitz is quite explicit: it is impossible "to construct a model for the art of war that can serve as a scaffolding on which the commander can rely for support at any time."[77] Since the opponent is a reacting, animate entity, "it is clear that continual striving after laws analogous to those appropriate to the realm of inanimate matter was bound to lead to one mistake after another."[78] The notion of law does not apply to actions in war, "since no prescriptive formulation universal enough to deserve the name of law can be applied to the constant change and diversity of the phenomena of war."[79] Thus theory must be based on a broader sense of order rooted in historical experience, leading to descriptive guidelines. Theorists must not be seduced into formulating analytically deductive, prescriptive sets of doctrines that offer poor hope and worse guidance.

Implications

I have demonstrated that Clausewitz perceives war as a profoundly nonlinear phenomenon that manifests itself in ways consistent with our current understanding of nonlinear dynamics. Furthermore, I have suggested that the predominance of a linear approach to analysis has made it difficult to assimilate and appreciate the intent and contribution of *On War*. The concepts and sensibility recently emerging in nonlinear science can be used to clarify not

75. *On War*, p. 80.
76. Ibid., p. 141.
77. Ibid., p. 140.
78. Ibid., p. 149.
79. Ibid., p. 152.

his confusion, but *our* truncated expectations for a theory of war—namely that it should conform to the restrictions of linearity. At the very least, such a sensibility may help us explore the stubborn intractability of prediction in war.[80] Only a few other implications can be noted here.[81]

One implication is that full comprehension of the work of Clausewitz demands that we retrain our intuition. For historians, who have often been attracted rather than repelled by the subtleties in *On War,* this may not be too unsettling a task. But for those trained in the engineering and scientific fields, as are so many military officers and analysts, this retraining is likely to be a more wrenching and unwelcome experience. As the various scientists and mathematicians cited above have suggested, the predominance of a linear intuition is endemic. Such an intuition guides value judgments and choices, with real world consequences:

> We would emphasize that in many areas of science and technology a large effort has traditionally been made to model a physical system or process. Yet once the mathematical model has been constructed, only a few rather cursory computer time simulations are sometimes made. Lulled into a false sense of security by his familiarity with the *unique* response of a linear system, the busy analyst or experimentalist shouts "Eureka, this is the solution" once a simulation settles onto an equilibrium or steady cycle, without bothering to explore patiently the outcome from different starting conditions. To avoid potentially dangerous errors and disasters, industrial designers must be prepared to devote a greater percentage of their effort to exploring the full range of dynamic responses of their systems.[82]

Here, Michael Thompson and Bruce Stewart speak of modeling physical systems and processes that are much simpler than the social systems engaged

80. Such an exploration would have immediate consequences. As Joshua Epstein has mused, "If, by a series of empirically and theoretically defensible assumptions, we are led to mathematical models that, over certain ranges, exhibit highly sensitive, even chaotic, behavior, that may reveal a fundamental fact about war and its inherent volatility, a fact with which policymakers, scholars, and soldiers may have to come to terms." Epstein, "The 3:1 Rule, the Adaptive Dynamic Model, and the Future of Security Studies," *International Security,* Vol. 13, No. 3 (Spring 1989), p. 119.

81. A parallel reexamination has begun in economics. In contrast to the negative-feedback idealizations of conventional theory, W. Brian Arthur has argued that positive feedbacks can make the history of an economic system matter. Thus, "to the extent that small events determining the overall path always remain beneath the resolution of the economist's lens, accurate forecasting of an economy's future may be theoretically, not just practically, impossible." Arthur, "Positive Feedbacks in the Economy," *Scientific American,* February 1990, p. 99. See also the essays in Philip W. Anderson, Kenneth J. Arrow, and David Pines, eds., *The Economy as an Evolving Complex System,* Santa Fe Institute *Studies in the Sciences of Complexity,* Vol. 5 (Redwood City, Calif.: Addison-Wesley, 1988).

82. Thompson and Stewart, *Nonlinear Dynamics and Chaos,* p. xiii.

in warfare, yet surveys of military applications of modeling indicate the predominance of the same analytically linear intuition despite the loss of realism it entails.[83] And, of course, the "potentially dangerous errors and disasters" take on added dimensions when the task is to prepare for or conduct a war.

A consequent necessity is a reevaluation of Clausewitz as an authority in military manuals and training. The simplicity of a set of "principles of war" will surely remain attractive, not least because they are so easy to comprehend and memorize. But we should understand that Clausewitz's concerns are to such principles as nonlinearity is to linearity (or fractals to Euclidean objects, or the real numbers to the integers). The elegance of military axioms is a mirage shimmering above the distant abstractions of implicitly idealized, isolated systems; the denseness of Clausewitz's forest of caveats and qualifications more faithfully represents the conditions and contexts we actually encounter.

Another implication of the nonlinear interpretation of Clausewitz is the need for a deepening of our understanding of his dictum on the relationship of war to politics. That "war is merely the continuation of policy by another means" is often taken to mean the primacy of a temporal continuum: first politics sets the goals, then war occurs, and then politics reigns again when the fighting stops. But such a view categorizes politics as extrinsic to war, and is an artifact of a linear sequential model. Politics is about power, and the feedback loops from violence to power and from power to violence are an intrinsic feature of war. It is not simply that political considerations weigh upon military commanders. War is inherently a subset of politics, and *every* military act has political consequences, whether or not these are intended or immediately obvious. In the grip of battle, it is hard to remember that every building destroyed, every prisoner taken, every combatant killed, every civilian assaulted, every road used, every unintentional violation of the customs of an ally ultimately has political import. It is crucial to understand that Clausewitz, who was for many years on the losing side before the tide turned against Napoleon, embeds the long-term view and the full range of a system's behavior into the structure of *On War.* Such considerations often make sol-

83. See John A. Battilega and Judith K. Grange, *The Military Applications of Modeling* (Wright-Patterson Air Force Base, Ohio: Air Force Institute of Technology Press, 1979), esp. Appendix A, pp. 516–543; and Battilega and Grange, *Models, Data, and War: A Critique of the Foundation for Defense Analyses* (Washington, D.C.: U.S. General Accounting Office, 1980).

diers impatient with his presentation, but the variables in war cannot be isolated from the parameters constituting the political context. And that environment itself evolves dynamically in response to the course of a war, with the changed context feeding back into the conduct of hostilities.

Yet another implication is that chance is also not extrinsic to war, because the interactive nature of military action itself *generates* chance. Single-valued, analytically exact solutions achieved by idealizations that conveniently excise all but a few variables derive from a linear intuition. Clausewitz understands that war has no distinct boundaries and that its parts are interconnected. What is needed is to comprehend intuitively both that the set of parameters for "the problem" is unstable, and that no arbitrarily selected part can be abstracted adequately from the whole. The work of Clausewitz indicates that knowing how the system functions at this moment does *not* guarantee that it will change only slightly in the next. Although it might remain stable, it might also suddenly (although perhaps subtly) pass a threshold into a thoroughly different regime of behavior. And the causes of such changes in a complex system can be imperceptibly small. Production of an unchanging set of laws or even principles to be employed in all "similar" contexts is not merely useless, it can become counterproductive and lead to the kind of fixed, inflexible, mechanical mentality that is overwhelmed by events. Adaptability is as important in doctrine as on the battlefield.

The overall pattern is clear: war seen as a nonlinear phenomenon—as Clausewitz sees it—is inherently unpredictable by analytical means. Chance and complexity dominate simplicity in the real world. Thus no two wars are ever the same. No war is guaranteed to remain structurally stable. No theory can provide the analytical short-cuts necessary to allow us to skip ahead of the "running" of an actual war. No realistic assumptions offer a way to bypass these uncomfortable truths. Yet these truths have the virtue that they help us identify the blinders we impose on our thinking when we attempt to linearize. And what Clausewitz says about the conduct of war applies to the study of war: "once barriers—which in a sense consist only in man's ignorance of what is possible—are torn down, they are not so easily set up again."[84]

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84. *On War*, p. 593.